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Walker

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(54) **CALIBRATION BATH WITH ACOUSTIC LIQUID LEVEL SENSOR**

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G01F 23/296 (2006.01)
G01K 15/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G01F 23/296*** (2013.01); ***G01K 15/002*** (2013.01); ***G01K 15/005*** (2013.01); *G01F 23/2962* (2013.01)

(58) **Field of Classification Search**
CPC . G01F 23/296; G01F 23/2962; G01K 15/002; G01K 15/005
See application file for complete search history.

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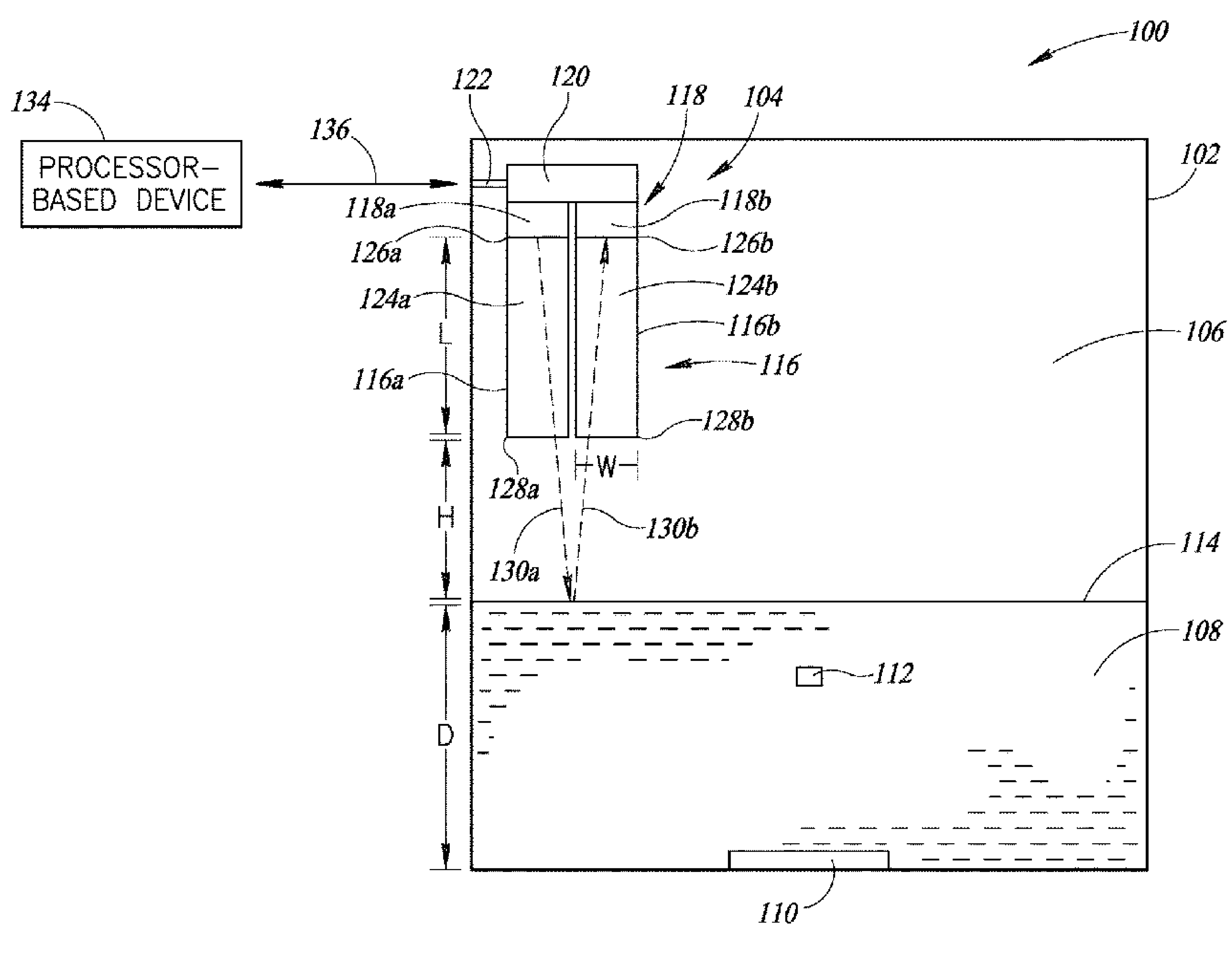
(57) **ABSTRACT**

Systems and methods that provide measurement of liquid levels in a container, such as a calibration bath container, may utilize an acoustic transducer subsystem that includes one or more acoustic transducers that are controlled by a controller. The acoustic transducer subsystem emits acoustic signals toward a surface of a liquid in a container, and detects reflected acoustic signals that are reflected from the surface of the liquid. The liquid level sensor utilizes an acoustic waveguide subsystem to allow the acoustic transducer subsystem to be spaced apart from the liquid, which protects the acoustic transducer system another other components from damage due to heat, liquid, and vapor. The acoustic waveguide subsystem also channels the emitted and reflected acoustic signals to prevent substantial scattering of the signals within the container, which greatly improves the accuracy of the liquid level sensor.

25 Claims, 7 Drawing Sheets



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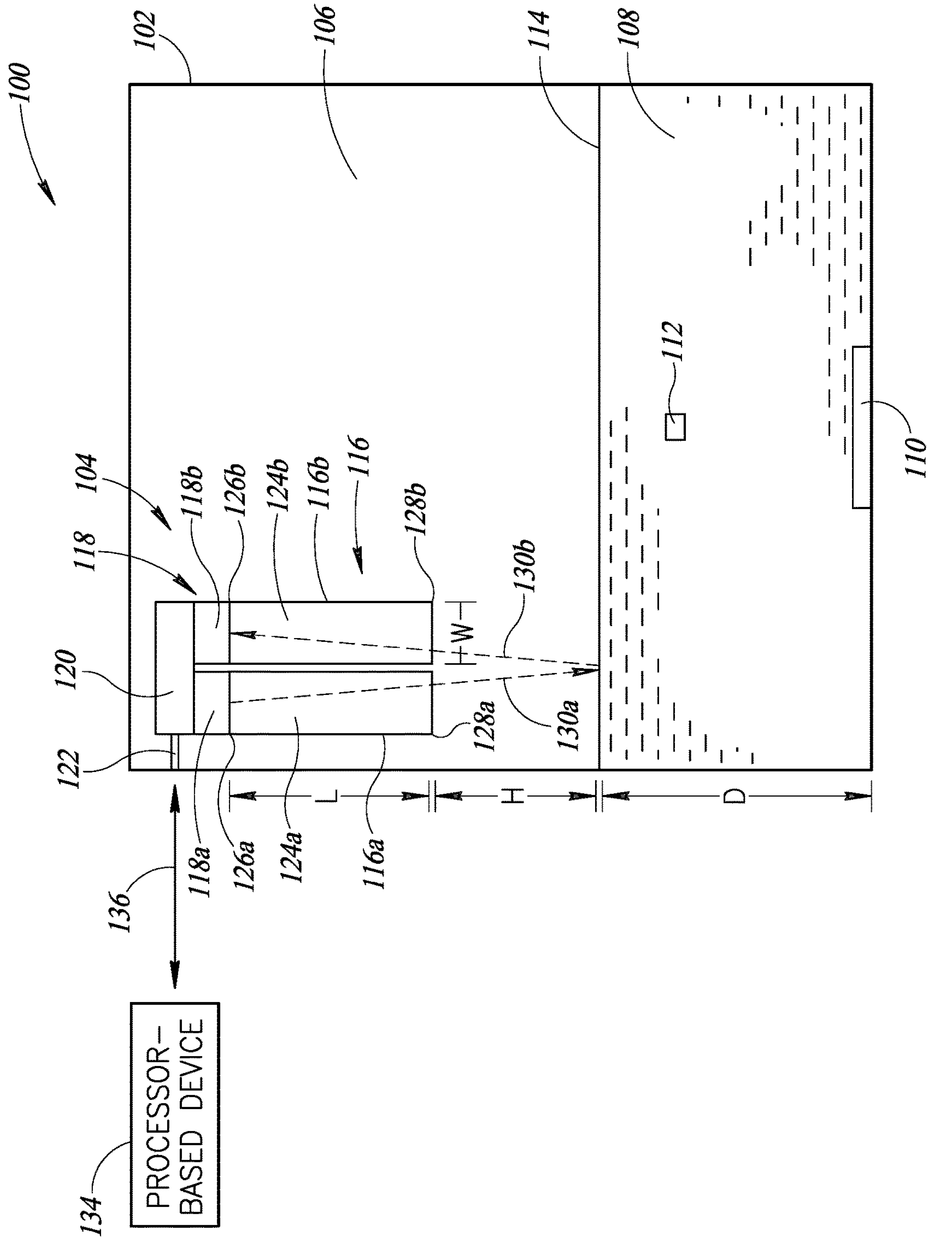
100
102
106
114
108
112
110
104
118
118b
126b
124b
116b
116
128b
130b
120
130a
128a
122
L
H
D
W
118a
126a
124a
116a
136
PROCESSOR-
BASED DEVICE
134

FIG. 1

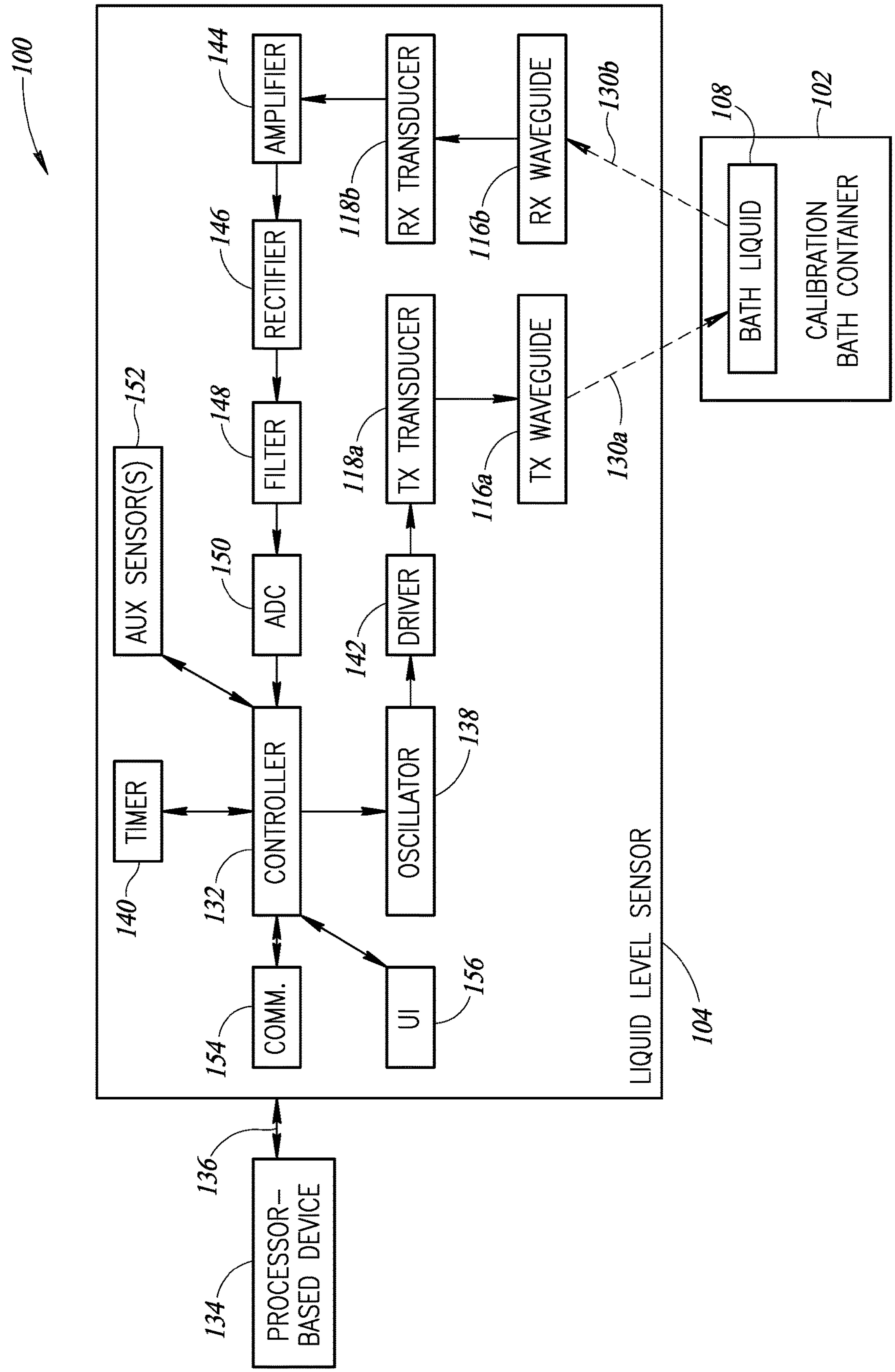
100
AMPLIFIER
144
RX TRANSDUCER
118b
RX WAVEGUIDE
116b
130b
108
102
BATH LIQUID
CALIBRATION
BATH CONTAINER
RECTIFIER
146
TX TRANSDUCER
118a
TX WAVEGUIDE
116a
130a
FILTER
148
AUX SENSOR(S)
152
ADC
150
DRIVER
142
CONTROLLER
132
TIMER
140
OSCILLATOR
138
COMM.
154
UI
156
LIQUID LEVEL SENSOR
104
PROCESSOR-
BASED DEVICE
134
136

FIG. 2

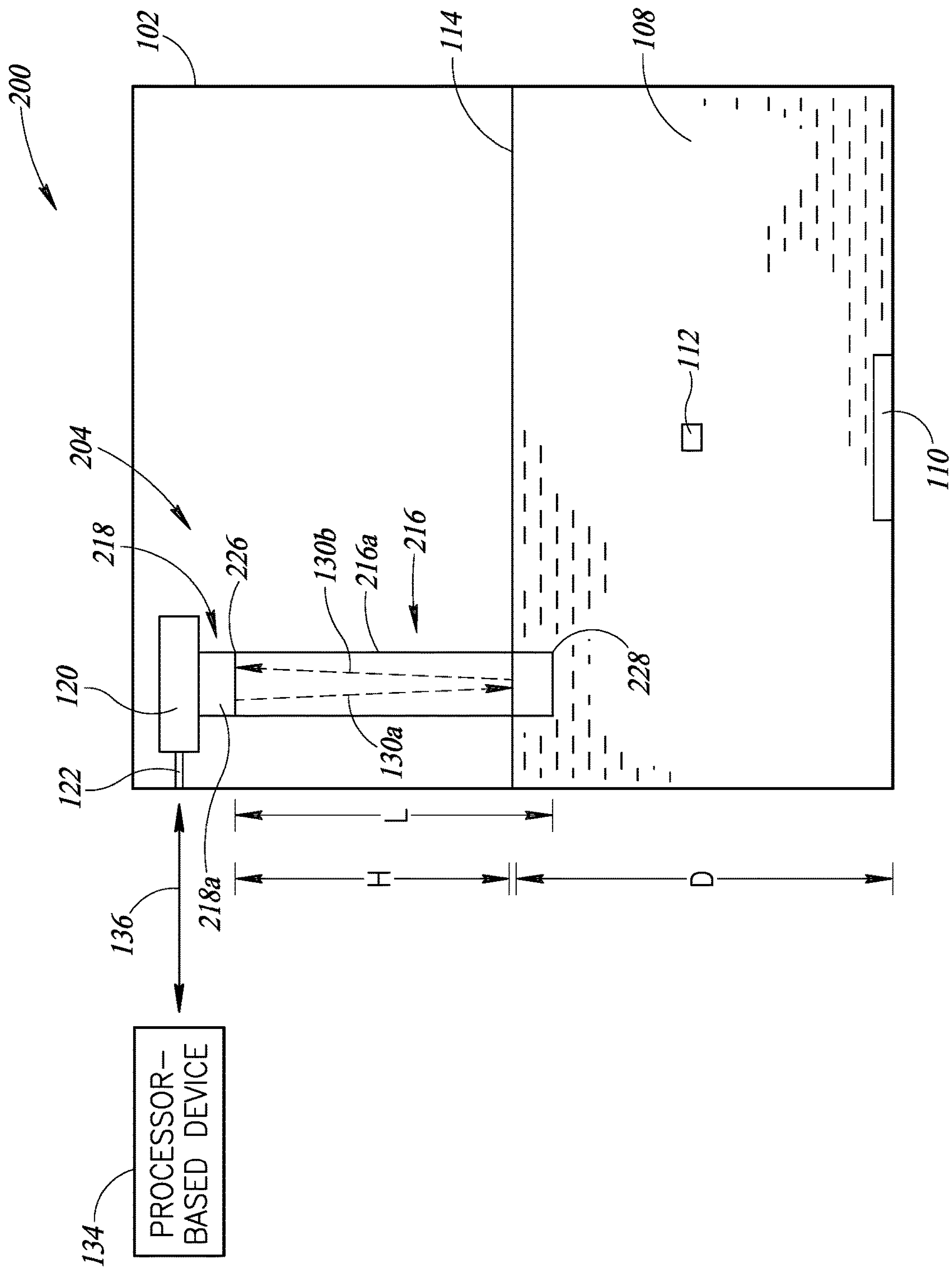
200
102
114
108
112
110
204
218
226
130b
216a
216
120
122
228
130a
L
H
D
218a
136
PROCESSOR–
BASED DEVICE
134

FIG. 3

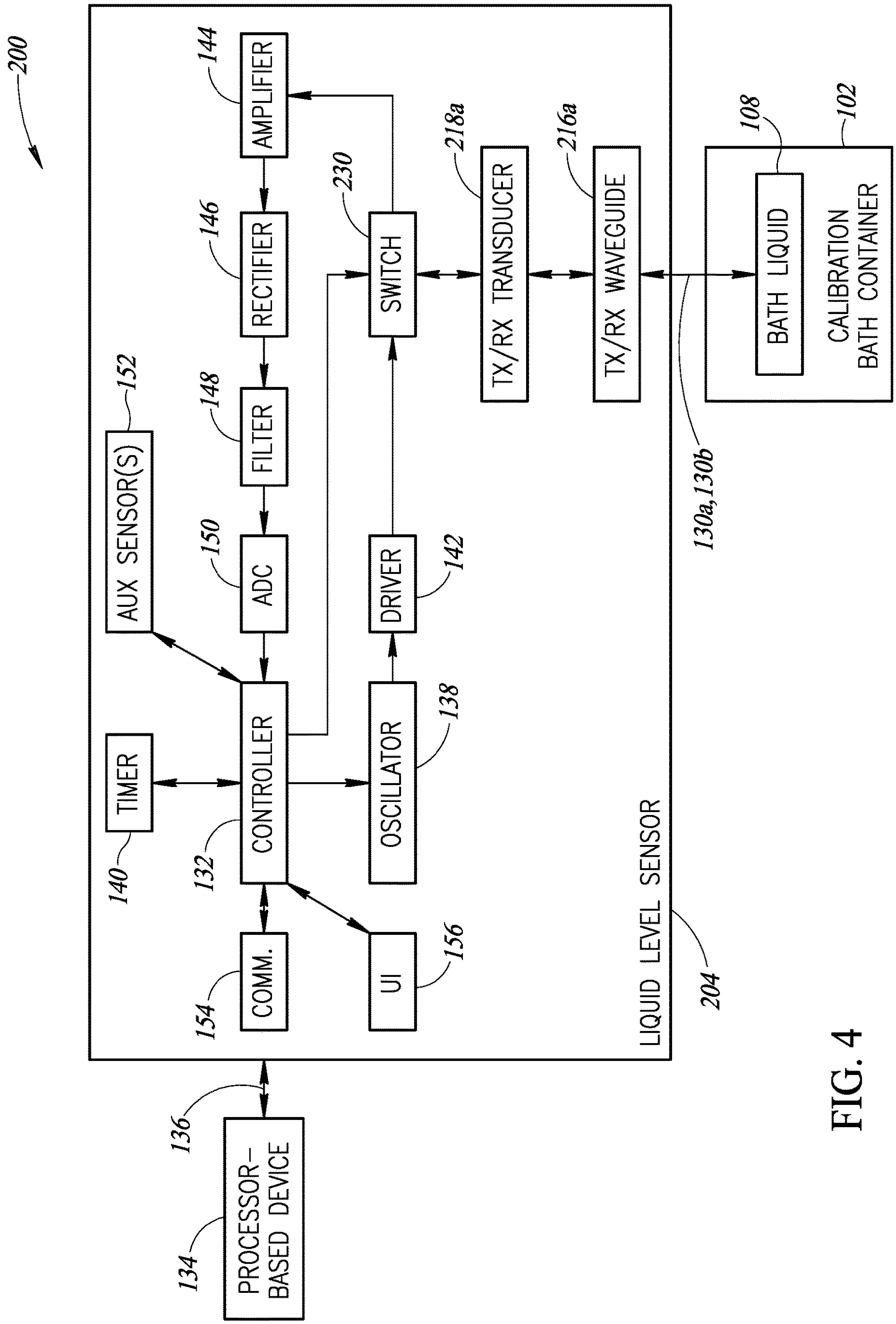
200
AMPLIFIER
144
RECTIFIER
146
FILTER
148
ADC
150
AUX SENSOR(S)
152
TIMER
140
CONTROLLER
132
COMM.
154
UI
156
SWITCH
230
DRIVER
142
OSCILLATOR
138
TX/RX TRANSDUCER
218a
TX/RX WAVEGUIDE
216a
LIQUID LEVEL SENSOR
204
130a,130b
BATH LIQUID
108
CALIBRATION BATH CONTAINER
102
PROCESSOR-BASED DEVICE
134
136

FIG. 4

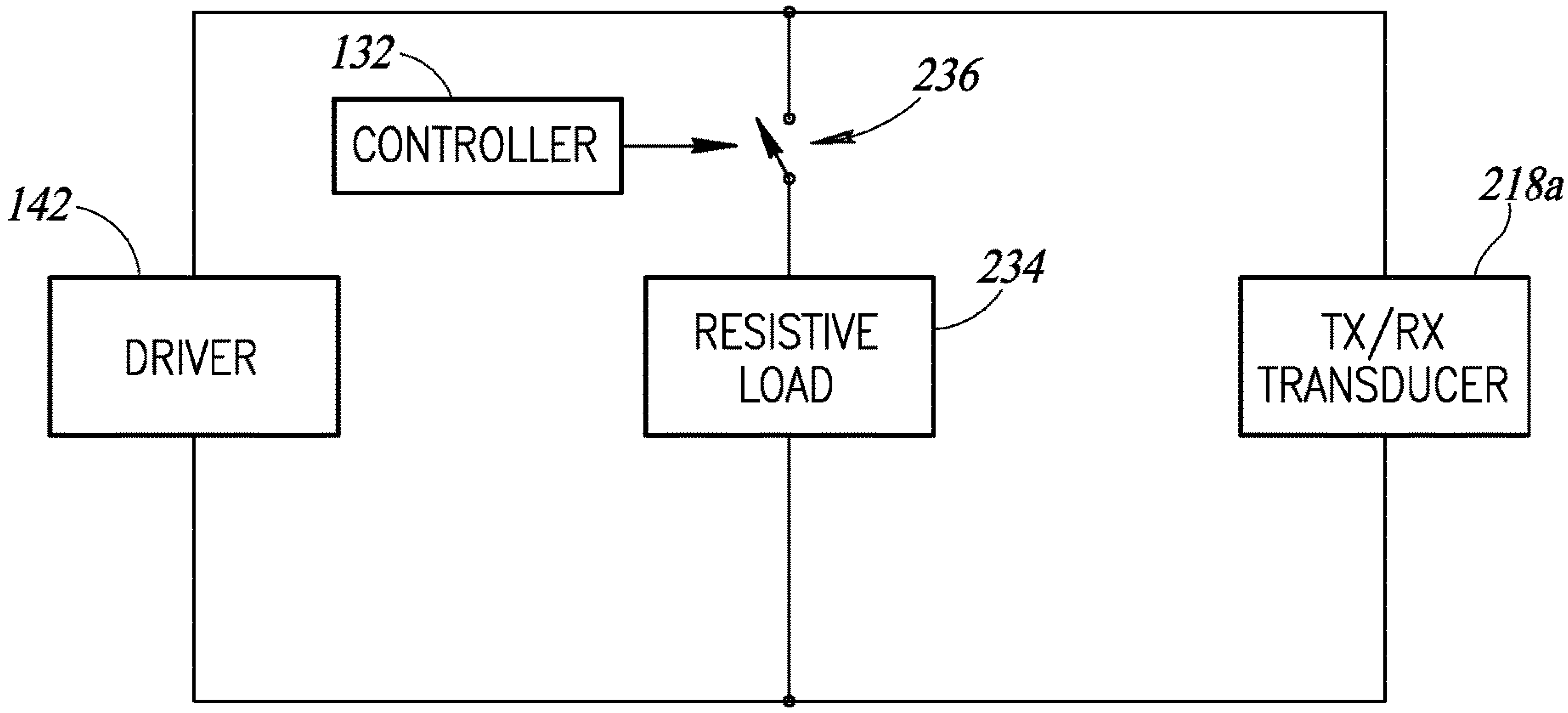
132
CONTROLLER
236
142
218a
234
DRIVER
RESISTIVE LOAD
TX/RX TRANSDUCER

FIG. 5

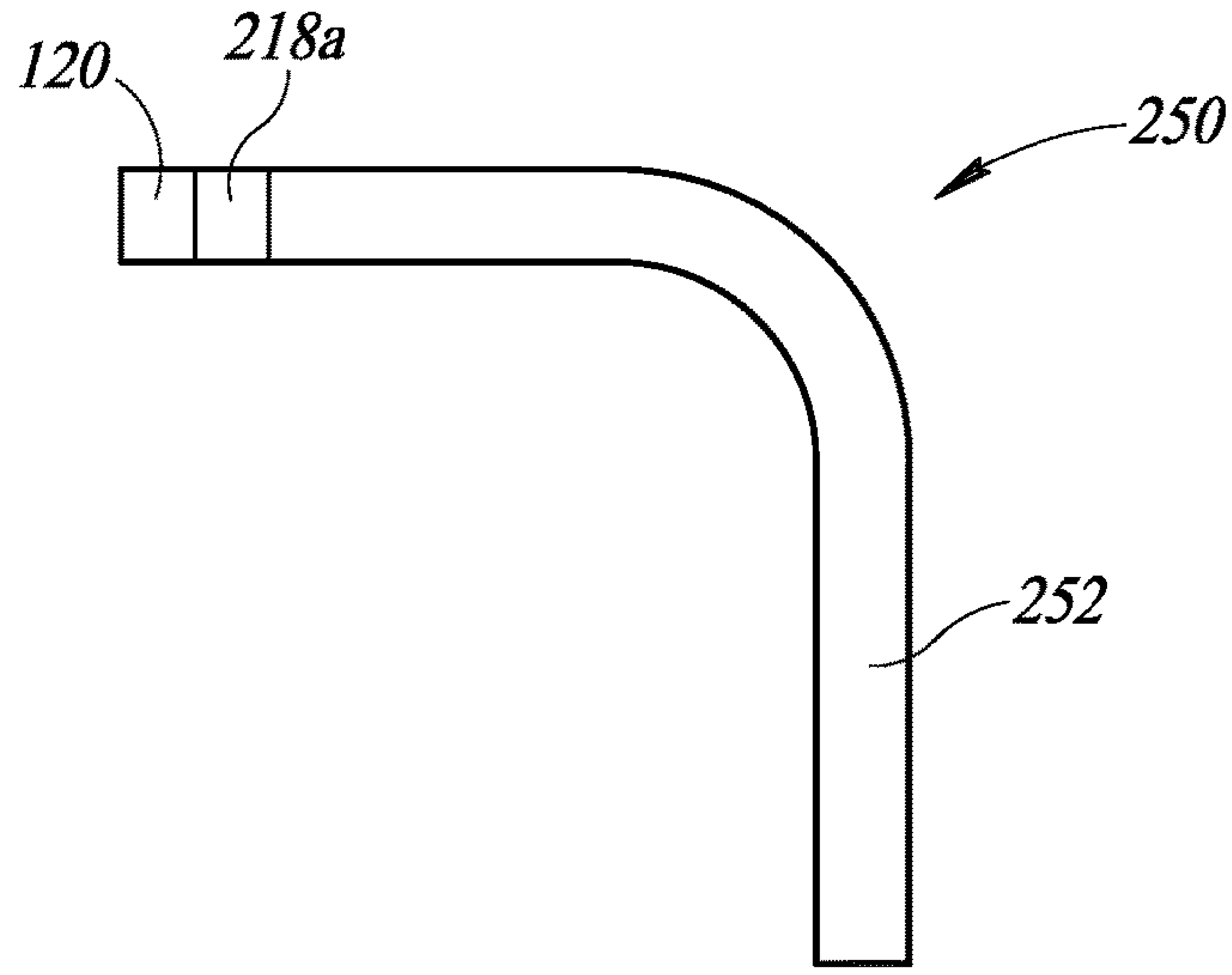
120
218a
250
252

FIG. 6

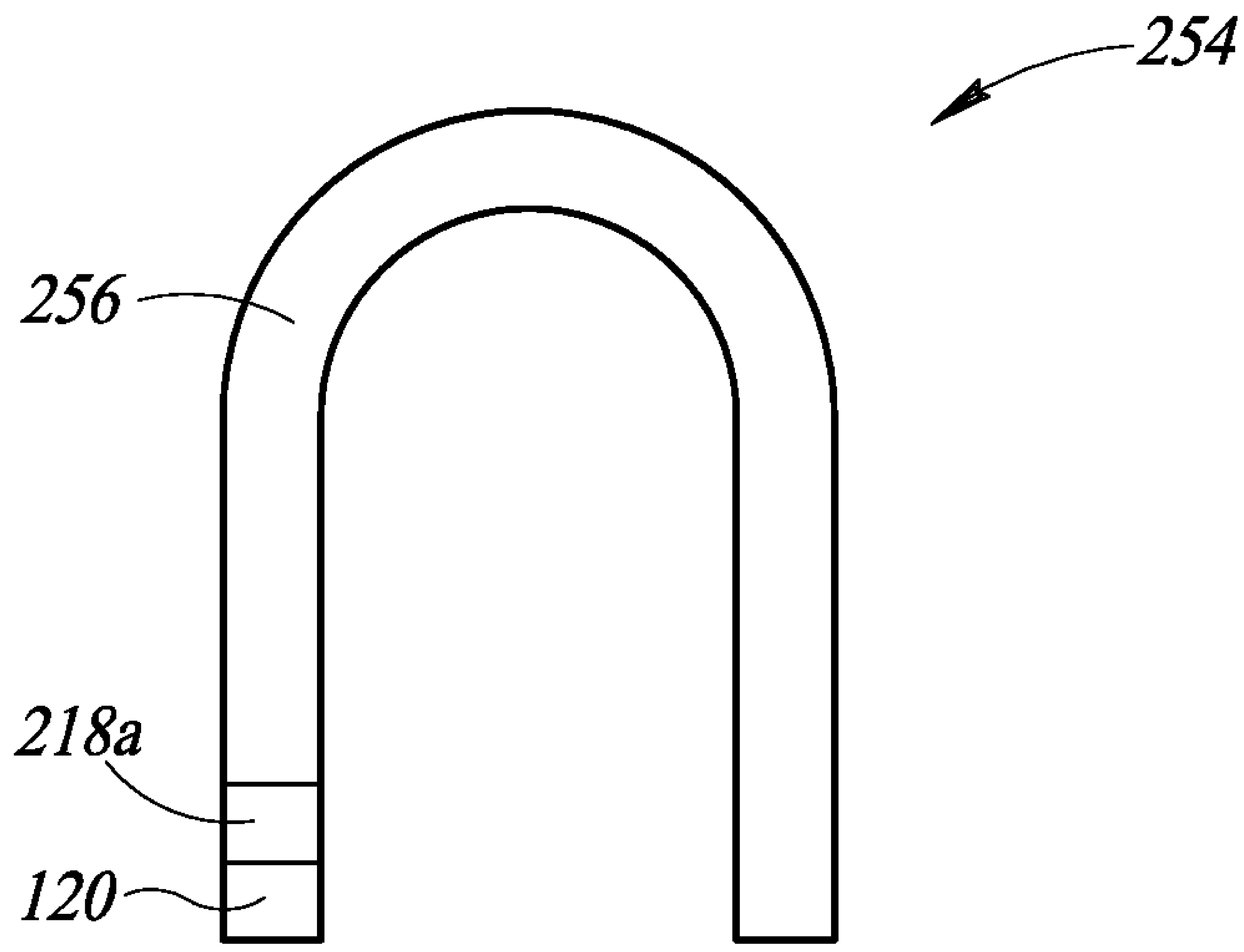

FIG. 7

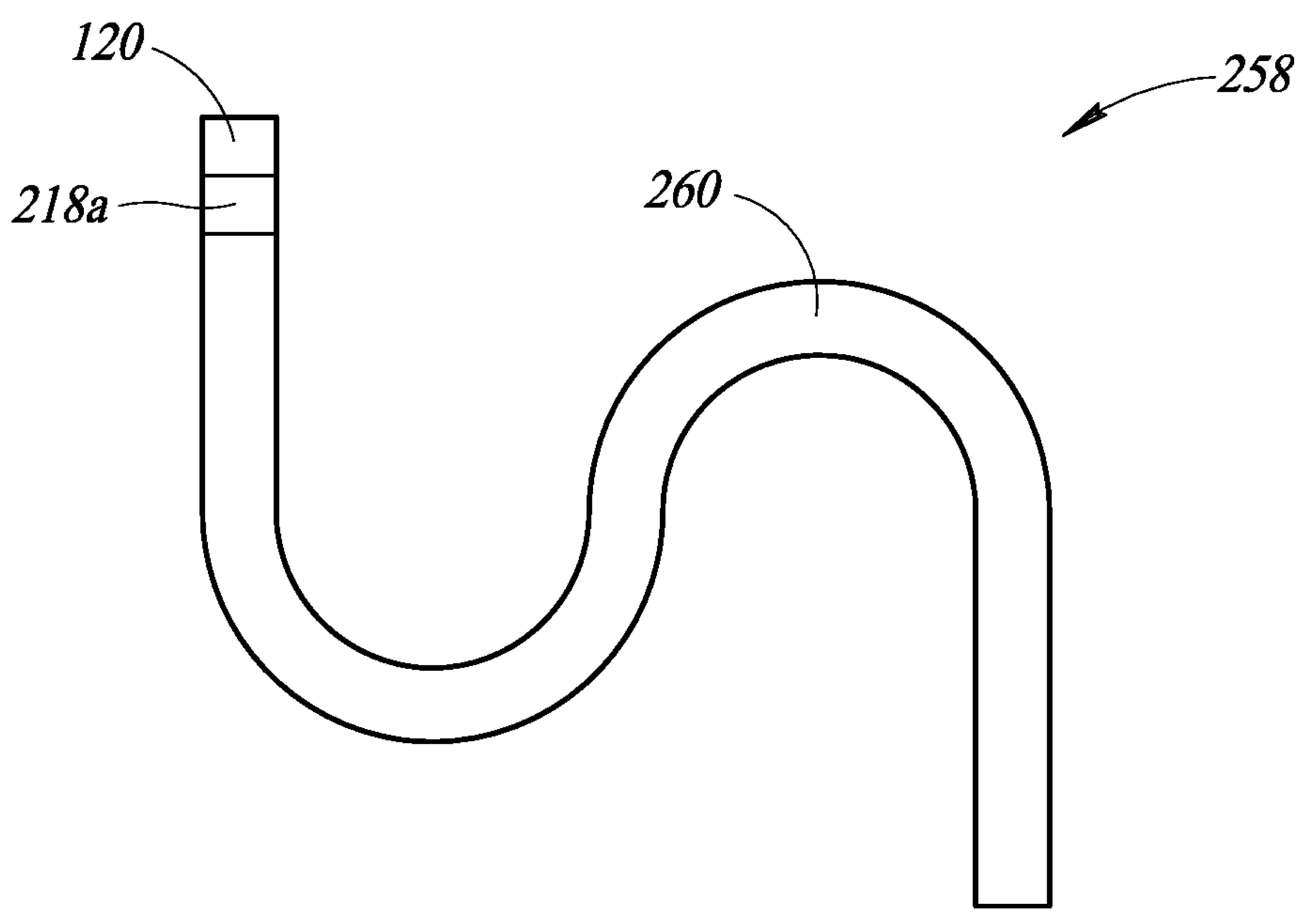

FIG. 8

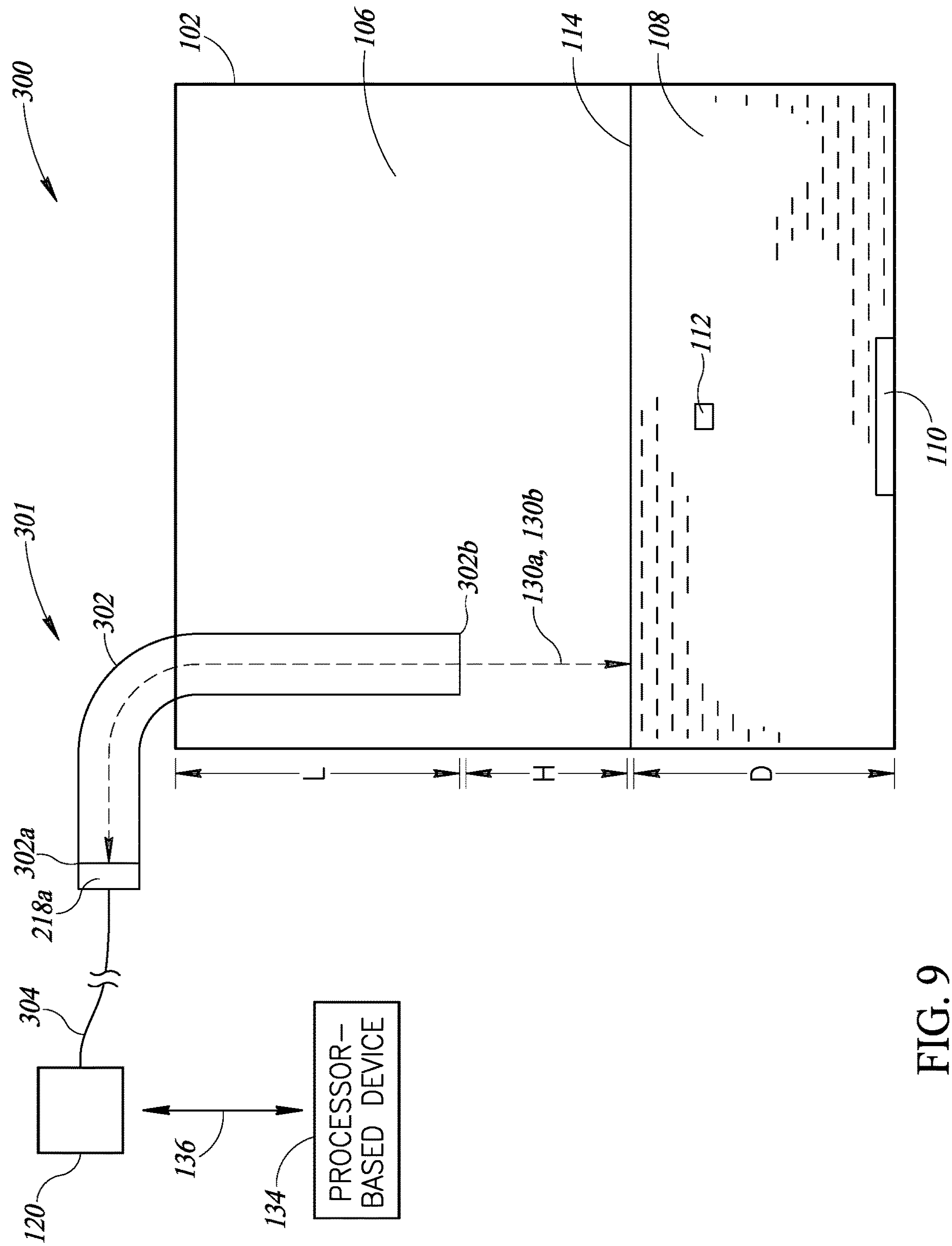
300
301
302
302a
302b
218a
304
120
136
134
PROCESSOR–
BASED DEVICE
102
106
114
108
112
110
130a, 130b
L
H
D

FIG. 9

CALIBRATION BATH WITH ACOUSTIC LIQUID LEVEL SENSOR

BACKGROUND

Technical Field

The present disclosure generally relates to sensors that utilize acoustic signals to determine a level of a liquid in a container, such as a calibration bath container.

Description of the Related Art

A calibration bath container, or "calibration bath," is commonly used in the calibration of temperature transducers and other types of temperature sensors. Typically, a calibration bath includes a tank or container filled with a liquid that is temperature controlled by one or more heaters and/or cooling assemblies. For optimal performance and safety, it can be important that the liquid in the calibration bath container be maintained at a proper level. A liquid level sensor would be useful for this purpose. However, for many applications, the temperature of the liquid in the calibration bath may be very high (e.g., 500° C. or higher). Such high temperatures preclude use of many types of available liquid level sensing technologies. As a result, most calibration baths do not have a liquid level sensor. Instead, an operator is required to visually check the bath fluid regularly to ensure the liquid is at the proper level. Failure to monitor the liquid level can lead to poor calibration results or even safety concerns. For example, if there is insufficient fluid in the calibration bath, heated parts of the calibration bath container can reach excessive temperatures. To help prevent damage to the calibration bath or materials, the equipment may need to be fitted with a cut-out device that disables the heaters if the heaters become too hot.

Previous calibration baths that have had a liquid level sensor have used a float-type liquid level sensor. There are practical limitations to such types of sensors. For example, such sensors can only be used in applications that utilize moderate temperature ranges. Additionally, float-type liquid level sensors are troublesome to clean and maintain, and are difficult to ensure reliability over time.

BRIEF SUMMARY

In at least some implementations, a liquid level sensor positionable with respect to a calibration bath container that holds a quantity of a liquid may be summarized as including: an acoustic waveguide subsystem comprising a sidewall that forms at least one elongated channel between a first end and a second end, the second end comprising at least one opening that faces toward the liquid in the calibration bath container; an acoustic transducer subsystem disposed proximate the first end of the acoustic waveguide subsystem, the acoustic transducer subsystem operative to transmit and detect acoustic signals via the acoustic waveguide subsystem; at least one nontransitory processor-readable storage medium that stores at least one of processor-executable instructions or data; and at least one processor communicatively coupled to the acoustic transducer subsystem and the at least one nontransitory processor-readable storage medium, wherein in operation, the at least one processor: causes the acoustic transducer subsystem to transmit an acoustic signal; causes the acoustic transducer subsystem to detect a reflected acoustic signal, the reflected acoustic signal being reflected from a surface of the liquid in the calibration bath container; receives a signal representative of the reflected acoustic signal; and determines a liquid parameter associated with an amount of the liquid in the calibration bath container based at least in part on a characteristic of the reflected acoustic signal.

The acoustic waveguide subsystem may include a single waveguide, and the acoustic transducer subsystem may include a transmit/receive transducer disposed proximate the first end of the acoustic waveguide subsystem, wherein in operation the transmit/receive transducer transmits and detects acoustic signals via the waveguide. The liquid level sensor may include a switch operatively coupled to the transmit/receive transducer, wherein in operation the switch alternatively couples the transmit/receive transducer to transmit circuitry or receive circuitry of the liquid level sensor, and wherein, in operation, the at least one processor controls the switch to couple the transmit/receive transducer to the transmit circuitry during a transmit phase in which the transmit/receive transducer transmits acoustic signals, and controls the switch to couple the transmit/receive transducer to the receive circuitry during a receive phase in which the transmit/receive transducer receives acoustic signals. The liquid level sensor may include a resistive load continuously or selectively coupled to the transmit/receive transducer. In operation, the at least one processor may cause delivery of a dampening pulse signal to the transmit/receive transducer between the transmit phase and the receive phase, the dampening pulse signal being out of phase with the pulse signal delivered to the transmit/receive transducer during the transmit phase. The second end of the acoustic waveguide subsystem may be submerged in the liquid in the calibration bath container when the liquid is within an intended range of levels.

In at least some implementations, the second end of the acoustic waveguide subsystem may be spaced apart from the liquid in the calibration bath container by between 1 centimeter and 50 centimeters when the liquid is within an intended range of levels, for example.

The acoustic waveguide subsystem may include a transmit waveguide and a receive waveguide, each of the transmit waveguide and receive waveguide including respective first and second ends, the second ends each including an opening that faces toward the liquid in the calibration bath container, and the acoustic transducer subsystem may include a transmit transducer and a receive transducer, the transmit transducer disposed proximate the first end of the transmit waveguide, and the receive transducer disposed proximate the first end of the receive waveguide. The transmit waveguide and the receive waveguide may be positioned substantially adjacent one another. The at least one elongated channel of the acoustic waveguide subsystem may have at least one curved portion. The acoustic waveguide subsystem may be formed from at least one of stainless steel, titanium, or polyvinyl chloride. The at least one elongated channel of the acoustic waveguide subsystem may have a length that is between 5 centimeters and 25 centimeters, for example. The elongated channel may have a cross-sectional area that is between 15 square millimeters and 150 square millimeters, for example.

The transmitted acoustic signal may result from a driving pulse signal including a number of cycles of at least one of a square wave, a triangle wave, or a sine wave. The liquid parameter may include at least one of: a depth of the liquid in the calibration bath container, a volume of the liquid in the calibration bath container, or a distance between the liquid level sensor and the surface of the liquid in the calibration bath container, for example. The characteristic of the reflected acoustic signal may include an elapsed travel time between when the acoustic signal is transmitted and when the reflected acoustic signal is detected.

The liquid level sensor may further include an auxiliary sensor operatively coupled to the at least one processor, wherein in operation, the at least one processor receives an auxiliary sensor signal from the auxiliary sensor and determines the liquid parameter based at least in part on the received auxiliary sensor signal. The auxiliary sensor may include at least one of a temperature sensor or a pressure sensor.

The liquid level sensor may further include a user interface operatively coupled to the at least one processor, wherein in operation, the at least one processor causes the user interface to provide an indication associated with the determined liquid parameter. The liquid level sensor may further include a communications interface operatively coupled to the at least one processor, wherein in operation, the at least one processor causes the communications interface to send information associated with the determined liquid parameter to a separate processor-based device.

At least a portion of the sidewall of the acoustic waveguide subsystem may be positionable outside of the calibration bath container during use. The at least one processor may be positionable outside of the calibration bath container during use. The acoustic transducer subsystem may be positionable outside of the calibration bath container during use.

In at least some implementations, a sensor calibration system may be summarized as including: a calibration bath container sized and dimensioned to hold a quantity of a liquid; a liquid level sensor positionable with respect to the calibration bath container, the liquid level sensor including: an acoustic waveguide subsystem including a sidewall that forms at least one elongated channel between a first end and a second end, the second end including at least one opening that faces toward the liquid in the calibration bath container; an acoustic transducer subsystem disposed proximate the first end of the acoustic waveguide subsystem, the acoustic transducer subsystem operative to transmit and detect acoustic signals via the acoustic waveguide subsystem; and control circuitry communicatively coupled to the acoustic transducer subsystem that. In operation, the control circuitry: causes the acoustic transducer subsystem to transmit an acoustic signal; causes the acoustic transducer subsystem to detect a reflected acoustic signal, the reflected acoustic signal reflected from a surface of the liquid in the calibration bath container; receives a signal representative of the reflected acoustic signal; and determines a liquid parameter associated with an amount of the liquid in the calibration bath container based at least in part on a characteristic of the reflected acoustic signal.

In at least some implementations, a method of operating a sensor calibration system may be summarized as including: positioning a liquid level sensor proximate a calibration bath container that holds a quantity of a liquid. The liquid level sensor may include: an acoustic waveguide subsystem including a sidewall that forms at least one elongated channel between a first end and a second end, the second end including at least one opening that faces toward the liquid in the calibration bath container; and an acoustic transducer subsystem disposed proximate the first end of the acoustic waveguide subsystem, the acoustic transducer subsystem operative to transmit and detect acoustic signals via the acoustic waveguide subsystem. The method may further include: causing, by at least one processor, the acoustic transducer subsystem to transmit an acoustic signal; causing, by the at least one processor, the acoustic transducer subsystem to detect a reflected acoustic signal, the reflected acoustic signal reflected from a surface of the liquid in the calibration bath container; receiving, by the at least one processor, a signal representative of the reflected acoustic signal; and determining, by the at least one processor, a liquid parameter associated with an amount of the liquid in the calibration bath container based at least in part on a characteristic of the reflected acoustic signal.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

In the drawings, identical reference numbers identify similar elements or acts. The sizes and relative positions of elements in the drawings are not necessarily drawn to scale. For example, the shapes of various elements and angles are not necessarily drawn to scale, and some of these elements may be arbitrarily enlarged and positioned to improve drawing legibility. Further, the particular shapes of the elements as drawn, are not necessarily intended to convey any information regarding the actual shape of the particular elements, and may have been solely selected for ease of recognition in the drawings.

FIG. **1** is an elevational view of a sensor calibration system that includes a calibration bath container and an acoustic liquid level sensor that includes a transmit acoustic transducer and a receive acoustic transducer, according to one illustrated implementation.

FIG. **2** is a schematic block diagram of the sensor calibration system of FIG. **1**, according to one illustrated implementation.

FIG. **3** is an elevational view of another sensor calibration system that includes a calibration bath container and an acoustic liquid level sensor that includes a single transmit/receive transducer, according to one illustrated implementation.

FIG. **4** is a schematic block diagram of the sensor calibration system of FIG. **3**, according to one illustrated implementation.

FIG. **5** is a schematic block diagram of a portion of an acoustic liquid level sensor, showing a resistive load selectively coupled in parallel with a transmit/receive transducer of the acoustic liquid level sensor, according to one illustrated implementation.

FIG. **6** is an elevational view of an example liquid level sensor that includes an acoustic waveguide formed into an "L" shape, according to one illustrated implementation.

FIG. **7** is an elevational view of an example liquid level sensor that includes an acoustic waveguide formed into a "U" shape, according to one illustrated implementation.

FIG. **8** is an elevational view of an example liquid level sensor that includes an acoustic waveguide formed into an "S" shape, according to one illustrated implementation.

FIG. **9** is an elevational view of a sensor calibration system that includes a calibration bath container and an acoustic liquid level sensor, wherein the liquid level sensor includes a waveguide that extends outside of the calibration bath container, according to one illustrated implementation.

DETAILED DESCRIPTION

One or more implementations of the present disclosure are directed to systems and methods of sensing a liquid level in a calibration bath using at least one acoustic (e.g., ultrasonic) transducer. Unique features of the implementations described herein allow the liquid level sensor, and various components associated therewith, to be located some distance from the bath liquid where the liquid level sensor is not affected by extreme temperatures, splashing liquid, or vapor. Such systems and methods provide a safer and more convenient solution that preemptively warns an operator in instances where the liquid level of a calibration bath is too low. In at least some implementations, the liquid level sensor may be operative to disable or modify operation of the calibration bath if the liquid level is too low. Solutions of the present disclosure provide greater convenience, broader temperature range capabilities, lower cost, and better reliability than presently available solutions.

In the following description, certain specific details are set forth in order to provide a thorough understanding of various disclosed implementations. However, one skilled in the relevant art will recognize that implementations may be practiced without one or more of these specific details, or with other methods, components, materials, etc. In other instances, well-known structures associated with computer systems, server computers, and/or communications networks have not been shown or described in detail to avoid unnecessarily obscuring descriptions of the implementations.

Unless the context requires otherwise, throughout the specification and claims that follow, the word "comprising" is synonymous with "including," and is inclusive or open-ended (i.e., does not exclude additional, unrecited elements or method acts).

Reference throughout this specification to "one implementation" or "an implementation" means that a particular feature, structure or characteristic described in connection with the implementation is included in at least one implementation. Thus, the appearances of the phrases "in one implementation" or "in an implementation" in various places throughout this specification are not necessarily all referring to the same implementation. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more implementations.

As used in this specification and the appended claims, the singular forms "a," "an," and "the" include plural referents unless the context clearly dictates otherwise. It should also be noted that the term "or" is generally employed in its sense including "and/or" unless the context clearly dictates otherwise.

The headings and Abstract of the Disclosure provided herein are for convenience only and do not interpret the scope or meaning of the implementations.

FIG. **1** shows a sensor calibration system **100** that includes a calibration bath container **102** and an acoustic liquid level sensor **104**. The calibration bath container **102** includes an interior volume **106** that holds a quantity of a liquid **108** and a heater **110** that may be controlled to heat the liquid to a desired temperature. The liquid **108** may have a depth D. In operation, one or more sensors **112** (e.g., temperature transducers) may be placed in the bath liquid **108** when the liquid is heated to a known temperature to calibrate or otherwise test the operation of the one or more sensors.

At least a portion of the liquid level sensor **104** may be positioned within at least a portion of the interior volume **106** of the calibration bath container **102** above a liquid surface **114** of the liquid **108** in the calibration bath container. The liquid level sensor **104** includes an acoustic waveguide subsystem **116**, an acoustic transducer subsystem **118**, and a housing **120** that contains various components discussed further below with reference to FIG. **2**.

In the illustrated example, the housing **120** of the liquid level sensor **104** is fixedly or removably attached to a surface of the calibration bath container **102** by one or more suitable fasteners **122** (e.g., bracket, clamp, bolt). In at least some implementations, the liquid level sensor **104** may be integrated with the calibration bath container **102**. In at least some implementations, the liquid level sensor **104** may be separate from the calibration bath container **102** such that the liquid level sensor may be used with numerous calibration bath containers having similar or different shapes and sizes.

The acoustic waveguide subsystem **116** includes a transmit waveguide **116*a*** and a receive waveguide **116*b*** (collectively "waveguides **116**"). The transmit waveguide **116*a*** comprises a continuous sidewall having a length L that forms an elongated hollow channel **124*a*** between a first end **126*a*** and a second end **128*a***, the second end **128*a*** including an opening that faces downward toward the liquid **108** in the calibration bath container **102**. Similarly, the receive waveguide **116*b*** comprises a continuous sidewall having a length L that forms an elongated hollow channel **124*b*** between a first end **126*b*** and a second end **128*b***, the second end **128*b*** including an opening that faces downward toward the liquid **108** in the calibration bath container **102**.

The second ends **128*a*** and **128*b*** of the waveguides **116*a*** and **116*b***, respectively, are spaced apart from the surface **114** of the liquid **108** by a height H, which varies dependent on the depth D of the liquid. In at least some implementations, the mounting position of the liquid level sensor **104** and/or the length L of the waveguides **116** are designed such that the second ends **128*a*** and **128*b*** are positioned between 1 cm and 50 cm from the surface **114** of the liquid **108** for the intended range of the depth D of the liquid, for example. In at least some implementations, the waveguides **116** may each have a length L that is between 5 cm and 25 cm (e.g., 10 cm, 20 cm). In the illustrated example, the waveguides **116** are positioned substantially adjacent each other (e.g., spaced apart by 0.1 cm, or in contact with each other), but in other implementations the waveguides may be spaced farther apart from each other. As discussed further below, the waveguides **116** may be formed into various shapes and sizes. Further, the shape and size of the transmit waveguide **116*a*** may the same as or different from the shape and size of the receive waveguide **116*b***.

Each of the waveguides may have a width dimension W that is selectable based on the particular application. As a non-limiting example, in at least some implementations, each of the waveguides **116** has an interior wall having a circular cross-section with a diameter that is between 0.2 cm and 2.5 cm (e.g., 0.6 cm). In at least some implementations, each of the waveguides **116** forms an elongated channel having a cross-sectional area that is between 15 square millimeters and 150 square millimeters, for example. The cross-sectional shape of the waveguides **116** may be any suitable shape (e.g., hexagonal, pentagonal, rectangular, triangular, circular, irregular shape). Further, the waveguides **116** may be formed from any suitable material, such as stainless steel, titanium, polyvinyl chloride (PVC), etc., or other suitable material. In at least some implementations, the waveguides **116** are formed from any material that is resistant to temperature, liquid, or vapor, and does not significantly dampen acoustic signals that traverse the waveguides.

In this illustrated implementation, the acoustic transducer subsystem **118** of the liquid level sensor **104** includes a transmit (TX) transducer **118*a*** positioned at the first end **126*a*** of the transmit waveguide **116*a***, and a receive (RX) transducer **118*b*** positioned at the first end **126*b*** of the receive waveguide **116***b*. The transmit transducer **118***a* is operative to transmit acoustic signals, indicated by dashed arrow **130***a*, through the transmit waveguide **116***a* of the acoustic waveguide subsystem **116**, and the receive transducer **118***b* is able to receive or otherwise detect reflected acoustic signals, indicated by dashed arrow **130***b* propagated through the receive waveguide **116***b* after reflection from the surface **114** of the liquid **108**. The transducers **118***a* and **118***b* may be piezoelectric transducers or other suitable types of acoustic transducers.

As discussed further below with reference to FIG. **2**, the housing **120** of the liquid level sensor **104** includes a controller **132** (FIG. **2**) and other components that facilitate operation of the liquid level sensor. Generally, the controller **132** may include at least one processor communicatively coupled to the acoustic transducer subsystem **118** and to at least one nontransitory processor-readable storage medium that stores at least one of processor-executable instructions or data. The controller **132** may include any type of processing unit, such as one or more central processing units (CPUs), digital signal processors (DSPs), application-specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), programmable logic controllers (PLCs), artificial neural network circuits or systems, or any other discrete or integrated logic components. The nontransitory processor-readable storage medium coupled to the controller **132** may include any type of nontransitory volatile and/or non-volatile memory.

Under direction of the controller **132**, in operation, the transmit transducer **118***a* may transmit acoustic signals **130***a* during a transmit phase, and during a receive phase the receive transducer **118***b* may detect reflected acoustic signals **130***b* that are reflected from the surface **114** of the liquid **108** in the calibration bath container **102**. The controller **132** may receive a signal (e.g., digital signal, analog signal) representative of the reflected acoustic signal **130***b*, and may determine a liquid parameter (e.g., surface level, depth, volume) associated with the amount of the liquid **108** in the calibration bath container **102** based at least in part on a characteristic (e.g., elapsed time of flight) of the transmitted and reflected acoustic signal. For example, the controller **132** may determine the elapsed time between transmitting the acoustic signal and detecting the reflected acoustic signal. Such information may be used along with the known speed of sound through air to determine the distance between the liquid level sensor **104** and the surface **114** of the liquid **108**. This determined distance may also be used to determine the depth D of the liquid **108** given a known positioning of the acoustic transducers **118***a*, **118***b* relative to the bottom of the calibration bath container **102**. The detection cycle, which includes the transmit phase and the receive phase, may be repeated periodically (e.g., every 100 ms, every 1 second, every 10 seconds, every minute, every 10 minutes) during the normal operation of the liquid level sensor.

As discussed further below, the determined liquid parameter (e.g., surface level, depth, volume) may be used to monitor the conditions of the liquid **108**, and to provide signals that may be used to notify an operator of the sensor calibration system **100** of liquid levels that are outside a range of acceptable liquid levels, or to modify the operation of the sensor calibration system **100**. Such operational modification may include disabling or modifying the operation of the heater **110**, causing liquid to be added to or removed from the container **102**, etc.

As shown in FIG. **1**, the transducers **118***a* and **118***b* are located a distance (L+H) from the surface **114** of the liquid **108**, which advantageously avoids potential damage to the transducers that may otherwise be caused by heat, liquid, or vapor. By providing the waveguide subsystem **116** as described above, the acoustic signals **130***a* transmitted by the transmit transducer **118***a* are directed toward the surface **114** of the bath liquid **108** through the transmit waveguide **116***a*, and the reflected signals **130***b* are guided through the receive waveguide **116***b* to the receive transducer **118***b*. This feature greatly increases the sensitivity and accuracy of the liquid level sensor **104** by not allowing the acoustic signals **130***a* and **130***b* to scatter throughout the interior volume **106** of the calibration bath container **102**, while allowing the transducers **118***a* and **118***b* to be spaced apart from the liquid **108**.

In at least some implementations, the liquid level sensor **104** may be communicatively coupled to an external processor-based device **134** via one or more wired and/or wireless communications channels **136**. The external processor-based device **134** may be any of a number of devices, such as a server, cloud-based system, smartphone, tablet computer, laptop computer, wearable computer, etc. Non-limiting examples of wireless communications technologies include Wi-Fi®, Bluetooth®, Bluetooth® Low Energy, Zigbee®, 6LoWPAN®, Optical IR, wireless HART, etc. Non-limiting examples of wired communications technologies include USB®, Ethernet, PLC, HART, MODBUS, FireWire®, Thunderbolt®, etc. Examples of the signals or data that may be communicated to/from the external device **134** include, but are not limited to, liquid parameters (e.g., surface level, depth, volume), control instructions or data, firmware, historical data, etc.

Although in the example shown in FIG. **1** the liquid level sensor **104** is shown as being positioned fully inside the container **102**, in many implementations a portion of the waveguides **116** may extend outside the container, and the acoustic transducers **118** are also positioned outside of the container where they may be less affected by heat, vapor, etc. Further, in at least some implementations, the controller **132** and/or other components may be physically separated from the transducers **118** by a distance and communicatively coupled to the transducers via a suitable connection (e.g., wires, wireless connection). FIG. **9** shows a non-limiting example of such an implementation. It should be appreciated that the various examples discussed herein may include one or more components (e.g., transducers, electronics, housing, portion of a waveguide) that are positionable outside of the container **102** during operation of the liquid level sensor.

FIG. **2** shows a schematic block diagram of the sensor calibration system **100** shown in FIG. **1**. As noted above, operation of the liquid level sensor **104** is controlled by the controller **132**. During a transmit phase, the controller **132** may turn on an oscillator **138** for a brief period of time. At the same time, the controller **132** may start a timer **140** so the controller can measure the time elapsed between when an acoustic signal is transmitted and when a reflected acoustic signal is detected. The oscillator **138** produces a short-duration, high frequency electronic signal. The signal may be amplified by a driver circuit **142** to increase the power level to a level suitable to operate the transmit transducer **118***a*. The amplified signal is then applied to the transmit transducer **118***a*, which causes the transmit transducer to vibrate and produce a pulse of high frequency sound. The sound is channeled toward the liquid **108** through the transmit waveguide **116***a* that is coupled to the transmit transducer **118***a*.

During a receive phase, the acoustic signals reflect off of the surface of the bath liquid **108** and travel back through the receive waveguide **116***b* that is coupled to the receive transducer **118***b*. The reflected acoustic signals vibrate the receive transducer **118***b*, causing the receive transducer to produce an electronic signal. In the illustrated implementation, the electronic signal is amplified by an amplifier circuit **144**, rectified by a rectifier circuit **146**, and smoothed by a filter circuit **148**. The conditioned signal is fed to an analog-to-digital converter (ADC) **150**. Digital samples from the ADC **150** are received by the controller **132** and associated with time stamps obtained by the controller from the timer **140**.

The controller **132** analyzes the data to determine the time elapsed from when the acoustic signals were transmitted and when the reflected acoustic signals were received. Then, using a known calculation or mathematical formula that takes into account the speed of sound, the controller **132** determines the distance between the transducers **118** and the surface **114** of the liquid **108**. From the determined distance and the known positioning of the liquid level sensor **104** relative to the calibration bath container **102**, the controller **132** can determine the depth D (see FIG. **1**) of the bath liquid **108**. In at least some implementations, the liquid level sensor **104** may include one or more auxiliary sensors **152**, such as a temperature sensor or a pressure sensor. The speed of sound varies dependent on the temperature and pressure of the air. In some implementations, the controller **132** may receive signals from the one or more auxiliary sensors, and may account for the effect of various environmental factors (e.g., temperature, pressure) on the speed of sound when determining the liquid parameter (e.g., surface level, depth, volume) associated with the amount of liquid **108** in the container **102**. This feature ensures accurate measurements even in varying environmental conditions.

In at least some implementations, the liquid level sensor **104** may optionally include a communications interface **154** or a user interface **156**. The user interface **156** may facilitate user interaction with the liquid level sensor **104**. The user interface **156** may include any number of inputs (e.g., buttons, dials, switches, touch sensor) and any number of outputs (e.g., display, LEDs, speakers, buzzers). For example, the user interface may include inputs that allow an operator to modify one or more adjustable settings of the liquid level sensor **104**. Such settings may include, for example, acceptable depths for the liquid, acceptable volume of the liquid, acceptable distances between the liquid level sensor and the surface of the liquid, display settings, communications settings, etc. The communications interface **154** may implement one or more wired and/or wireless communications technologies (e.g., USB, Bluetooth®) that allow the controller **132** to communicate with one or more external processor-based devices, such as the illustrated processor-based device **134**, via one or more communications channels **136**.

After the controller **132** has determined the liquid parameter, such information may be presented to an operator or provided to a device for monitoring or control purposes. For example, the information may be presented to an operator via a display of the user interface **156** of the liquid level sensor **104**, or may be sent via the communication interface **154** to a device that includes a display. As another example, such information may be sent to a monitoring system that is operative to notify an operator when the level of the liquid **108** is determined to be outside a determined range of levels. In at least some implementations, the information may be used by the liquid level sensor **104** or another system to modify the operation of the sensor calibration system **100** by, for example, disabling or changing the operation of the heater **110** of the calibration bath container **102**.

As an example, the liquid level sensor **104** may be configured to define a liquid level depth range of between 5 and 50 centimeters, dependent on the sizes and dimensions of the container. For example, for a particular medium sized calibration bath, the acceptable range may be between 25 and 30 centimeters, below which range the acoustic liquid level sensor may trigger a warning or other action. The sensor **104** may periodically (e.g., every second, every minute, every hour) obtain a depth measurement and compare the depth measurement to the defined range. Responsive to detecting that the measured depth is outside the range, the liquid level sensor **104** may cause any number of notification and/or control actions to be implemented, as discussed elsewhere herein.

FIGS. **3** and **4** illustrate another implementation of a sensor calibration system **200** according to the present disclosure. Many of the features of the sensor calibration system **200** are similar or identical to the sensor calibration system **100** of FIGS. **1** and **2** discussed above. As such, some or all of the discussion above relating to the sensor calibration system **100** also applies to the sensor calibration system **200**.

The sensor calibration system **200** includes a liquid level sensor **204** that utilizes an acoustic transducer subsystem **218** that includes a single transmit/receive (TX/RX) transducer **218***a*, and an acoustic waveguide subsystem **216** that includes a single waveguide or tube **216***a*. The waveguide **216***a* includes a first end **226** proximate the transducer **218***a* and a second end **228** opposite the first end. In at least some implementations, the liquid level sensor **204** may be positioned inside the calibration bath container **102** such that the second end **228** of the waveguide **216** is submerged in the liquid **108** below the surface **114** thereof for the intended range of levels of the liquid. Such feature prevents acoustic signals **130***a* and **130***b* from being dispersed throughout the container **102**, which may improve the accuracy of the liquid level sensor **204**. In at least some implementations, the liquid level sensor **204** may include separate receive and transmit transducers, rather than a single transmit/receive transducer, disposed proximate the first end **226** the single waveguide **216***a*.

As discussed further below with reference to FIG. **4**, during operation, a switch **230** that is controlled by the controller **132** directs the flow of electronic signals to and from the transducer **218***a* so that transmit circuitry used during the transmit phase does not interfere with receive circuitry used during the receive phase.

Referring to the schematic block diagram of FIG. **4**, the controller **132** turns on the oscillator **138** for a brief time during the transmit phase. The controller **132** also sets the switch **230** so that the driver **142** is connected to the transducer **218***a* and the amplifier **144** is disconnected from the transducer. At the same time, the controller **132** starts the timer **140** so the controller can measure the time of the echo, as discussed above. The oscillator **138** produces a short-duration, high-frequency electronic signal. The signal is amplified by the driver **142**. The amplified signal flows through the switch **230** to the transducer **218***a*, which vibrates and produces a pulse of high frequency acoustic signals.

After the acoustic signals are emitted by the transducer **218***a*, and while the acoustic signals are traveling toward the liquid **108** or being reflected from the liquid, the controller **132** operates the switch **230** to disconnect the driver **142** from the transducer **218***a* and to connect the amplifier **114** to the transducer to initiate the receive phase. The emitted acoustic signals **130***a* are channeled toward the surface of the liquid **108** through the waveguide **216***a* connected to the transducer **218***a*. Inside the waveguide **216***a* the emitted acoustic signals reflect off of the surface of the liquid **108** and reflected signals travel back through the waveguide to the transducer **218***a*. The reflected acoustic signals vibrate the transducer **218***a*, producing an electrical signal. The electrical signal is conditioned by the amplifier circuit **144**, the rectifier circuit **146**, and the filter circuit **148**, as discussed above. The conditioned signal is converted to a digital signal by the ADC **150**, which digital signal is received by the controller **132**. As discussed above, the controller **132** analyzes the received digital signal and timing information from the timer **140** to determine a liquid parameter (e.g., surface level, depth, volume) of the liquid **108** in the calibration bath container.

In order for the transducer **218***a* to detect the reflected acoustic signals without interference, it may be advantageous for the transducer to stop vibrating before the reflected acoustic signals arrive at the transducer from the surface of the liquid **108**. This goal may be achieved using one or more of several methods. As a first example, the duration of the oscillating signal may be designed to be relatively short compared to the time required for the signals to travel to the surface of the liquid **108** and return. For example, in at least some implementations, the oscillating signal comprises a few cycles (e.g., 4 cycles, 8 cycles, 16 cycles) of a 40 kHz signal, which has a duration of approximately 0.2 ms.

FIG. **5** illustrates another method that may be used to actively dampen the transducer **218***a* after transmission and prior to reception. In this illustrated implementation, a resistive load **234** (e.g., resistor) is electrically coupled in parallel with the transducer **218***a*. The resistive load **234** functions to dampen the vibration of the transducer **218***a* after the transducer transmits the pulse signal. In some embodiments, the resistive load **234** is continuously electrically coupled with the transducer **218***a*. In other implementations, the connection of the resistive load **234** to the transducer **218***a* may be selectively controlled by a switch **236** that is controlled by the controller **132** or other circuitry. In such implementations, the resistive load **234** may be disconnected from the transducer **218***a* when the transducer is transmitting the pulse signal. Then, after the transducer **218***a* has transmitted the pulse signal, the switch **236** may be closed by the controller **132** for a brief duration of time between the transmit phase and the receive phase to connect the resistive load **234** to the transducer. The switch **236** may then be opened by the controller **132** prior to the expected time when the reflected acoustic signals will arrive at the transducer **218***a* such that the resistive load **234** is again disconnected from the transducer **218***a* when the reflected signals arrive at the transducer.

Another method that may be utilized to actively dampen the vibration of the transducer **218***a* includes driving the transducer with a brief "dampening" pulse signal that has the same frequency as the initial pulse but is out of phase (e.g., 180° out of phase) with the initial pulse. Such out of phase signal helps cause the transducer to cease vibrating. Continuing with the above example, if the initial pulse is 8 cycles of a 40 kHz sine wave, the "dampening" pulse signal delivered to the transducer may be a pulse that is 4 cycles of a 40 kHz sine wave having a relative phase of 180 degrees from the initial pulse delivered to the transducer during the transmit phase, for example. In at least some implementations, one or more (e.g., all) of the aforementioned techniques may be utilized to cause the transducer **218***a* to stop vibrating between the transmit phase and the receive phase.

FIGS. **6-8** show various implementations of liquid level sensors, illustrating non-limiting examples of various shapes that may be used for the waveguide subsystem (e.g., acoustic waveguide subsystem **116**, **216**). The examples shown in FIGS. **6-8** show waveguide subsystems that utilize a single waveguide (see FIGS. **3** and **4**), but it should be appreciated that similar shapes may be used for implementations that utilize separate transmit and return waveguides (see FIGS. **1** and **2**).

FIG. **6** shows a liquid level sensor **250** that includes an acoustic waveguide **252** formed into an "L" shape. FIG. **7** shows a liquid level sensor **254** that includes an acoustic waveguide **256** formed into a "U" shape. FIG. **8** shows a liquid level sensor **258** that includes an acoustic waveguide **260** formed into an "S" shape. In at least some implementations, the acoustic waveguides **252**, **256**, **260** may be formed of a rigid material (e.g., stainless steel). In at least some implementations, the acoustic waveguides **252**, **256**, **260** may be formed of a pliable or flexible material, such that the waveguides may be shaped by an operator to a suitable shape for a particular application.

FIG. **9** is an elevational view of a sensor calibration system **300** that includes a calibration bath container **102** and an acoustic liquid level sensor **301**. The liquid level sensor **301** includes a waveguide **302** having a first end **302***a* and a second end **302***b* opposite the first end. In this illustrated implementation, the first end **302***a* of the waveguide extends outside of the calibration bath container **102** when the liquid level sensor **301** is positioned for measurement of the one or more liquid parameters of the liquid **108** in the container **102**. Thus, the acoustic transducer **218***a* positioned proximate the first end **302***a* of the waveguide **302** is also positioned outside of the container **102**, where it may be less affected by heat, vapor, etc. Further, the housing **120** which includes various components (e.g., controller **132**, communications interface **154**, user interface **156**, etc.) may be physically separated from the transducer **218***a* by a distance and communicatively coupled to the transducer via a length of wire **304** or other suitable connection (e.g., one or more wires, wireless connection). Thus, in this implementation, the transducer **218***a* and the components in the housing **120** are further protected from heat, vapor, etc., from the liquid **108** in the container **102**.

The controller **132** may be any of a number of types of devices, such as a computer, microprocessor, microcontroller, field programmable gate array (FPGA), application specific integrated circuit (ASIC), or system of discrete components, that is capable of performing the functionality discussed herein. Additionally, some components, such as the timer **140**, oscillator circuit **138**, driver circuit **142**, and amplifier circuit **144**, may be separate components, subcircuits, or may be built-in functions of the controller **132**. In at least some implementations, one or more of the components may be combined or omitted, or the liquid level sensor may include additional components.

For example, some components, such as the ADC **150** or the rectifier circuit **146**, may not be required depending on the particular objectives and required precision. As an example, a circuit may simply produce a logic transition when the amplitude of a signal from the receive transducer (e.g., RX transducer **118***b*, transducer **218***a*) reaches a certain threshold. Such logic transition would be indicative of receipt of the echo signal, and may be used with a time stamp to determine the elapsed time of travel for the acoustic signal which, as discussed above, may be used to determine one or more parameters associated with the liquid **108** in the container **102**.

In at least some implementations, the controller **132** may not calculate the actual distance between the liquid level sensor and the surface of the liquid. For example, the controller **132** may decide whether the liquid level is acceptable simply based on whether the echo is detected within a window of time. The window of time may be selectively adjustable by a user to suit a particular application (e.g., particular size container). Further, although the pulse signal has been described as being a number (e.g., 4, 8, 12) of cycles of a 40 kHz sine wave in one or more example implementations, pulses having other frequencies (e.g., 200 Hz-100 kHz), shapes (e.g., triangle wave, square wave), and durations (e.g., 0.01 ms, 0.1 ms, 1.0 ms) may be used.

The foregoing detailed description has set forth various implementations of the devices and/or processes via the use of block diagrams, schematics, and examples. Insofar as such block diagrams, schematics, and examples contain one or more functions and/or operations, it will be understood by those skilled in the art that each function and/or operation within such block diagrams, flowcharts, or examples can be implemented, individually and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. In one implementation, the present subject matter may be implemented via Application Specific Integrated Circuits (ASICs). However, those skilled in the art will recognize that the implementations disclosed herein, in whole or in part, can be equivalently implemented in standard integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more controllers (e.g., microcontrollers) as one or more programs running on one or more processors (e.g., microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of ordinary skill in the art in light of this disclosure.

Those of skill in the art will recognize that many of the methods or algorithms set out herein may employ additional acts, may omit some acts, and/or may execute acts in a different order than specified.

In addition, those skilled in the art will appreciate that the mechanisms taught herein are capable of being distributed as a program product in a variety of forms, and that an illustrative implementation applies equally regardless of the particular type of signal bearing media used to actually carry out the distribution. Examples of signal bearing media include, but are not limited to, the following: recordable type media such as floppy disks, hard disk drives, CD ROMs, digital tape, and computer memory.

The various implementations described above can be combined to provide further implementations. These and other changes can be made to the implementations in light of the above-detailed description. In general, in the following claims, the terms used should not be construed to limit the claims to the specific implementations disclosed in the specification and the claims, but should be construed to include all possible implementations along with the full scope of equivalents to which such claims are entitled. Accordingly, the claims are not limited by the disclosure.

The invention claimed is:

1. A liquid level sensor positionable with respect to a calibration bath container that holds a quantity of a liquid, the calibration bath container comprising a controllable heater, and the liquid level sensor comprising:

an acoustic waveguide subsystem comprising a sidewall that forms at least one elongated channel between a first end and a second end, the second end comprising at least one opening that faces toward the liquid in the calibration bath container;

an acoustic transducer subsystem disposed proximate the first end of the acoustic waveguide subsystem, the acoustic transducer subsystem operative to transmit and detect acoustic signals via the acoustic waveguide subsystem;

at least one nontransitory processor-readable storage medium that stores at least one of processor-executable instructions or data; and

at least one processor communicatively coupled to the acoustic transducer subsystem, the controllable heater, and the at least one nontransitory processor-readable storage medium, wherein in operation, the at least one processor:

causes the acoustic transducer subsystem to transmit an acoustic signal;

causes the acoustic transducer subsystem to detect a reflected acoustic signal, the reflected acoustic signal being reflected from a surface of the liquid in the calibration bath container;

receives a signal representative of the reflected acoustic signal;

determines a liquid parameter associated with an amount of the liquid in the calibration bath container based at least in part on a characteristic of the reflected acoustic signal;

determines whether the liquid level of the liquid in the calibration bath container is outside a range of acceptable liquid levels based on the determined liquid parameter; and

responsive to a determination that the liquid level is outside the range of acceptable liquid levels, modifies the operation of the controllable heater of the calibration bath container.

2. The liquid level sensor of claim **1** wherein the acoustic waveguide subsystem comprises a single waveguide, and the acoustic transducer subsystem comprises a transmit/receive transducer disposed proximate the first end of the acoustic waveguide subsystem, wherein in operation the transmit/receive transducer transmits and detects acoustic signals via the waveguide.

3. The liquid level sensor of claim **2**, further comprising:

a switch operatively coupled to the transmit/receive transducer, wherein in operation the switch alternatively couples the transmit/receive transducer to transmit circuitry or receive circuitry of the liquid level sensor, and wherein, in operation, the at least one processor controls the switch to couple the transmit/receive transducer to the transmit circuitry during a transmit phase in which the transmit/receive transducer transmits acoustic signals, and controls the switch to couple the transmit/receive transducer to the receive circuitry during a receive phase in which the transmit/receive transducer receives acoustic signals.

4. The liquid level sensor of claim **3**, further comprising a resistive load continuously or selectively coupled to the transmit/receive transducer.

5. The liquid level sensor of claim **3** wherein, in operation, the at least one processor causes delivery of a dampening pulse signal to the transmit/receive transducer between the transmit phase and the receive phase, the dampening pulse signal being out of phase with the pulse signal delivered to the transmit/receive transducer during the transmit phase.

6. The liquid level sensor of claim **2** wherein the second end of the acoustic waveguide subsystem is submerged in the liquid in the calibration bath container when the liquid is within an intended range of levels.

7. The liquid level sensor of claim **1** wherein the second end of the acoustic waveguide subsystem is spaced apart from the liquid in the calibration bath container by between 1 centimeter and 50 centimeters when the liquid is within an intended range of levels.

8. The liquid level sensor of claim **1** wherein the acoustic waveguide subsystem comprises a transmit waveguide and a receive waveguide, each of the transmit waveguide and receive waveguide comprising respective first and second ends, the second ends each comprising an opening that faces toward the liquid in the calibration bath container, and the acoustic transducer subsystem comprises a transmit transducer and a receive transducer, the transmit transducer disposed proximate the first end of the transmit waveguide, and the receive transducer disposed proximate the first end of the receive waveguide.

9. The liquid level sensor of claim **8** wherein the transmit waveguide and the receive waveguide are positioned substantially adjacent one another.

10. The liquid level sensor of claim **1** wherein the at least one elongated channel of the acoustic waveguide subsystem has at least one curved portion.

11. The liquid level sensor of claim **1** wherein the acoustic waveguide subsystem is formed from at least one of stainless steel, titanium, or polyvinyl chloride.

12. The liquid level sensor of claim **1** wherein the at least one elongated channel of the acoustic waveguide subsystem has a length that is between 5 centimeters and 25 centimeters.

13. The liquid level sensor of claim **1** wherein the elongated channel has a cross-sectional area that is between 15 square millimeters and 150 square millimeters.

14. The liquid level sensor of claim **1** wherein the transmitted acoustic signal results from a driving pulse signal comprising a number of cycles of at least one of a square wave, a triangle wave, or a sine wave.

15. The liquid level sensor of claim **1** wherein the liquid parameter comprises at least one of: a depth of the liquid in the calibration bath container, a volume of the liquid in the calibration bath container, or a distance between the liquid level sensor and the surface of the liquid in the calibration bath container.

16. The liquid level sensor of claim **1** wherein the characteristic of the reflected acoustic signal comprises an elapsed travel time between when the acoustic signal is transmitted and when the reflected acoustic signal is detected.

17. The liquid level sensor of claim **1**, further comprising:
an auxiliary sensor operatively coupled to the at least one processor, wherein in operation, the at least one processor receives an auxiliary sensor signal from the auxiliary sensor and determines the liquid parameter based at least in part on the received auxiliary sensor signal.

18. The liquid level sensor of claim **17** wherein the auxiliary sensor comprises at least one of a temperature sensor or a pressure sensor.

19. The liquid level sensor of claim **1**, further comprising:
a user interface operatively coupled to the at least one processor, wherein in operation, the at least one processor causes the user interface to provide an indication associated with the determined liquid parameter,
wherein, responsive to a determination that the liquid level is outside the range of acceptable liquid levels, the at least one processor causes at least one notification that the liquid level is outside the range of acceptable liquid levels to be provided via the user interface.

20. The liquid level sensor of claim **1**, further comprising:
a communications interface operatively coupled to the at least one processor, wherein in operation, the at least one processor causes the communications interface to send information associated with the determined liquid parameter to a separate processor-based device,
wherein, responsive to a determination that the liquid level is outside the range of acceptable liquid levels, the at least one processor causes at least one notification that the liquid level is outside the range of acceptable liquid levels to be provided via the communications interface.

21. The liquid level sensor of claim **1** wherein at least a portion of the sidewall of the acoustic waveguide subsystem is positionable outside of the calibration bath container during use.

22. The liquid level sensor of claim **1** wherein the at least one processor is positionable outside of the calibration bath container during use.

23. The liquid level sensor of claim **1** wherein the acoustic transducer subsystem is positionable outside of the calibration bath container during use.

24. A sensor calibration system, comprising:
a calibration bath container sized and dimensioned to hold a quantity of a liquid, the calibration bath container comprising a controllable heater;
a liquid level sensor positionable with respect to the calibration bath container, the liquid level sensor comprising:
an acoustic waveguide subsystem comprising a sidewall that forms at least one elongated channel between a first end and a second end, the second end comprising at least one opening that faces toward the liquid in the calibration bath container;
an acoustic transducer subsystem disposed proximate the first end of the acoustic waveguide subsystem, the acoustic transducer subsystem operative to transmit and detect acoustic signals via the acoustic waveguide subsystem;
control circuitry communicatively coupled to the acoustic transducer subsystem and the controllable heater that, in operation:
causes the acoustic transducer subsystem to transmit an acoustic signal;
causes the acoustic transducer subsystem to detect a reflected acoustic signal, the reflected acoustic signal reflected from a surface of the liquid in the calibration bath container;
receives a signal representative of the reflected acoustic signal;
determines a liquid parameter associated with an amount of the liquid in the calibration bath container based at least in part on a characteristic of the reflected acoustic signal;
determines whether the liquid level of the liquid in the calibration bath container is outside a range of acceptable liquid levels based on the determined liquid parameter; and
responsive to a determination that the liquid level is outside the range of acceptable liquid levels,

modifies the operation of the controllable heater of the calibration bath container.

25. A method of operating a sensor calibration system, the method comprising:

positioning a liquid level sensor proximate a calibration bath container that holds a quantity of a liquid, the calibration bath container comprising a controllable heater, and the liquid level sensor comprising:

an acoustic waveguide subsystem comprising a sidewall that forms at least one elongated channel between a first end and a second end, the second end comprising at least one opening that faces toward the liquid in the calibration bath container; and

an acoustic transducer subsystem disposed proximate the first end of the acoustic waveguide subsystem, the acoustic transducer subsystem operative to transmit and detect acoustic signals via the acoustic waveguide subsystem;

causing, by at least one processor, the acoustic transducer subsystem to transmit an acoustic signal;

causing, by the at least one processor, the acoustic transducer subsystem to detect a reflected acoustic signal, the reflected acoustic signal reflected from a surface of the liquid in the calibration bath container;

receiving, by the at least one processor, a signal representative of the reflected acoustic signal;

determining, by the at least one processor, a liquid parameter associated with an amount of the liquid in the calibration bath container based at least in part on a characteristic of the reflected acoustic signal;

determining, by the at least one processor, whether the liquid level of the liquid in the calibration bath container is outside a range of acceptable liquid levels based on the determined liquid parameter; and

responsive to determining that the liquid level is outside the range of acceptable liquid levels, modifying, by the at least one processor, the operation of the controllable heater of the calibration bath container.

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